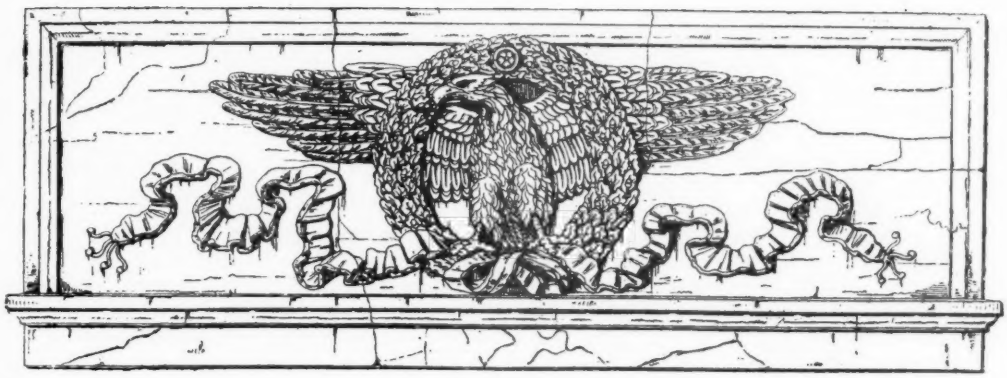


# THE AISLE VAULTING OF WINCHESTER TRANSEPT.

By John Bilson [*F.*], F.S.A.

THE recent publication in this Journal * of my friend Professor Charles H. Moore's admirable analysis of the aisle vaulting of Winchester transept suggests that it may be of interest to publish, with some explanatory notes, a drawing of the vaulting of one bay which I made eleven years ago, but have not hitherto published.

First, however, I should like to clear up two small points upon which the readers of Professor Moore's paper might possibly imagine that there was some difference between what he says and what I wrote in a paper published in this Journal in 1899, though no such difference exists.

Professor Moore quotes (p. 314) my statement that "in the reconstructed bays . . . the vaults were entirely rebuilt as ribbed vaults," and goes on to say that I qualified this by remarking that "in the northernmost bay of the east aisle of the north transept, which would not be affected by the fall of the tower, the vault itself does not appear to have been rebuilt, but the ribs seem to have been added under the original vault, and are backed out up to the groins." † This, however, is not a reconstructed bay, and I was more immediately interested in the vaulting of the bays which were entirely rebuilt after the fall of the central tower in 1107, adding a footnote in correction of a slip in Professor Willis's description. On referring to my notes, I find that they entirely agree with what Professor Moore says (p. 314), and that I grouped the vaults thus :—

Original vaults.‡ North transept : the two bays under the tribune ; and the first and second bays (counting from the north) of the western aisle. South transept : the two bays under the tribune.

Original vaults, with twelfth-century ribs added. North transept : the first bay of the eastern aisle.§ South transept : the first ‖ and second bays (counting from the south) of the eastern aisle. With later ribs added, the second bay of the eastern aisle of north transept.

Twelfth-century vaults. North transept : the third bay in the eastern aisle, and the third bay in the western aisle. South transept : the third bay in the eastern aisle, and the first, second, and third bays in the western aisle.¶

Professor Moore (p. 315) quotes my remark ** that "the haunches of the vault, for a short distance above the springing, are constructed of ashlar," and he suggests that this is an inadvertence. It is hardly that, though perhaps I must plead guilty to a loose use of the word "haunch."†† But I

* Third Series, Vol. XXIII. pp. 313–320 and 329–334.

† *The Beginnings of Gothic Architecture*, in the R.I.B.A. Journal, Third Series, Vol. VI., pp. 301–2.

‡ The building of the cathedral was begun in 1079, and the monks entered in 1093.

§ Professor Moore's B, Fig. 1, p. 314.

‖ Professor Moore's Fig. 10, p. 330.

¶ The above was written before I had seen Professor Moore's letter in the Journal for 11th November, p. 16.

** *Beginnings*, p. 293.

†† The *N.E.D.* defines "haunch" as "the side of an arch between the crown and the piers, the flank."

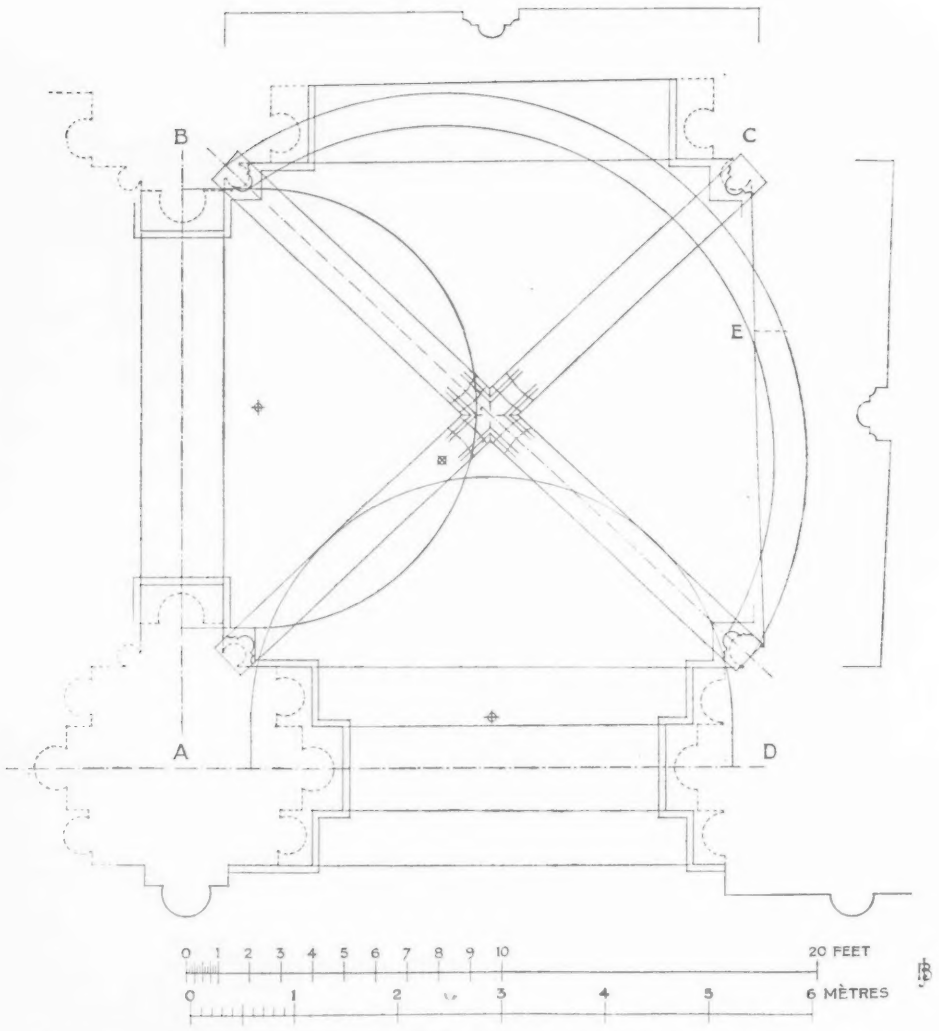
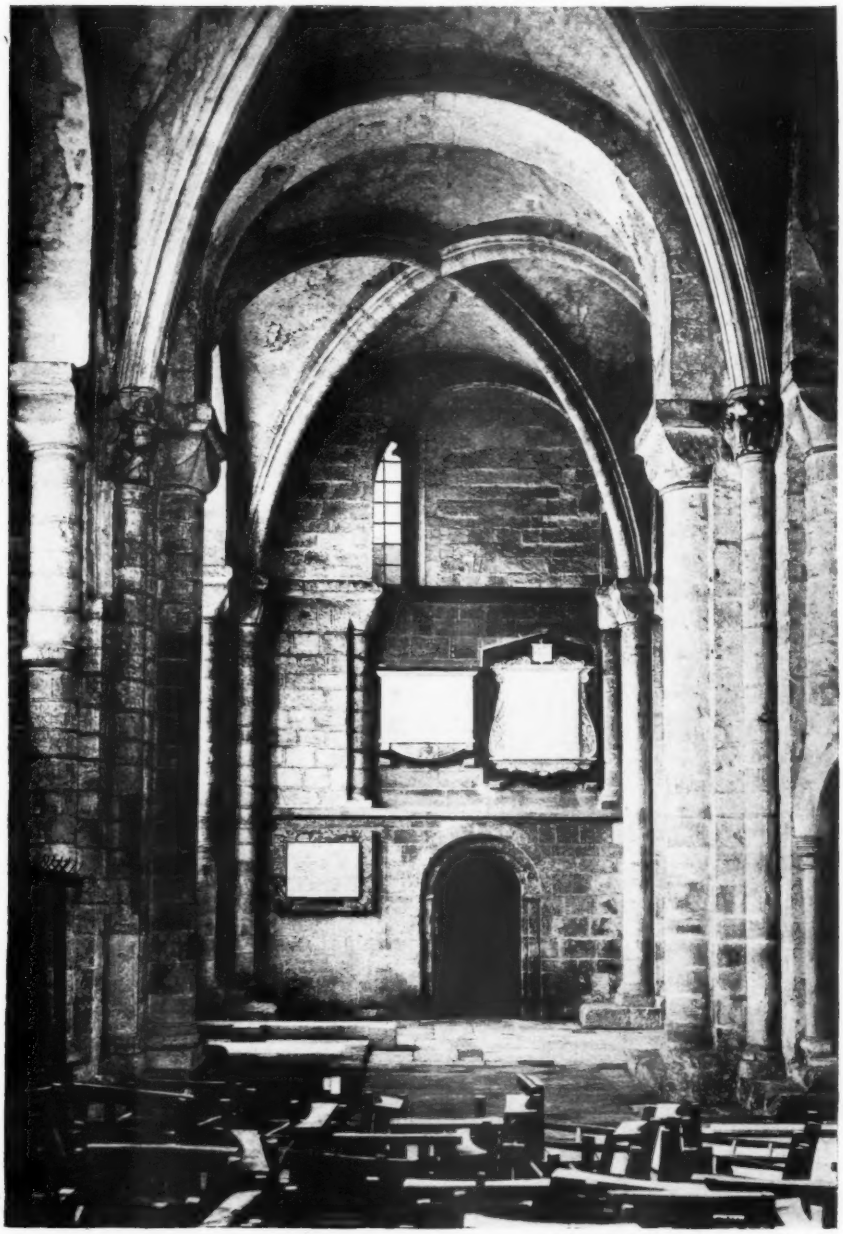



FIG. 1.—WINCHESTER, EAST AISLE OF NORTH TRANSEPT, THIRD BAY FROM NORTH: PLAN OF VAULT.



[*Chas. E. S. Beloe, Phot., Winchester.*

FIG. 2.—WINCHESTER, NORTH TRANSEPT, EAST AISLE, THIRD BAY FROM NORTH, LOOKING SOUTH.

qualified the word by " for a short distance above the springing," and the two illustrations (Figs. 3 and 4) on the opposite page show quite clearly what was meant. These ashlar springings of the groins of rubble vaults were a considerable step forward ; obviously it was much sounder construction to spring the vault from these worked blocks, instead of starting the groins from an internal angle with small bits of rubble. Moreover, at Winchester and elsewhere, following Saint-Etienne, Caen, the springings were logically received by their own shaft, constituting a further development of the articulation of the pier, in which, as in so many other things, the Norman Romanesque anticipated the methods of complete Gothic.*

The bay of the aisle vaulting illustrated by the drawing (Fig. 1) and the photograph (Fig. 2) is the third from the north, in the eastern aisle of the north transept—one of the bays near the crossing which were rebuilt after the fall of the central tower in 1107. The plan of the supports is indicated on Fig. 1 by dotted lines. The pier D and the wall as far as E are part of the twelfth-century rebuilding. The piers A, B, and C are the original eleventh-century work.

The arcade arch A D is a semicircle, stilted 1 foot 7 inches.† The transverse arch A B is a semicircle, stilted 2 feet 5 inches. These arches control the geometrical structure of the vault. Given that the crowns of the cells were to be level (and they are nearly so ‡), the height of the diagonal ribs was fixed, and their curves are segments of circles, struck from centres about 2 feet 1 inch below the springing line. The ribs spring from the shafts which, in the original work, were planned to receive the projecting groins of the unribbed vaults. The ribs are of thin stones, generally from 5 to 6 inches wide, and the joints are about $\frac{1}{4}$ inch thick, in marked contrast to the wide joints of the original masonry.

In the original unribbed vaults the rubble cells were, I suppose, built on semi-cylindrical centering continuous in one direction, with similar centering applied on each side for the lateral cells. § The groin, therefore, is not a designed curve, but simply the result of the intersection of the cells, or rather of the centering on which they were built. And the geometrical structure of the vault is controlled by the semicircular curve of the transverse and arcade arches.

This last remark is true also of the ribbed vaults (Fig. 1), which, as Professor Moore observes, still retain much of the method of the earlier vaults. The adoption of the semicircular curve for the diagonal rib, which then controlled the structure of the vault, followed very quickly in the Norman school, especially in high vaults, but the earlier method lasted long in aisle vaults.

The geometrical conformation of the cells in the ribbed vault, however, differs radically from that of the earlier unribbed vaults. The groin rib is a designed curve, built on its own centering, and the rubble cells were built on centering boards joining the curves of the arches and ribs, which necessarily causes the more or less pronounced ploughsharing of their surface which Professor Moore describes (p. 332).

The date of these ribbed vaults near the crossing is of considerable importance in relation to the chronology of the vaulted construction of the Norman school. The masonry of the ribs presents the same characteristics as that of the parts rebuilt after the fall of the tower, and there can be no doubt that these vaults were part of this general rebuilding. Professor Moore (p. 313) says that the date is uncertain, " though from the profiling and jointing of the ribs it would appear to have been considerably after the fall of the crossing tower," and he thinks that it could hardly have been before the second quarter of the twelfth century. If the profile of the rib in the bay illustrated in my Fig. 1 were as drawn in Professor Moore's Fig. 8 (p. 319), with the roll disengaged to the extent of nearly

* The projected towers at the ends of the transept are an instance of Norman anticipation of an idea afterwards realised at Chartres, Rouen, Reims, &c.

† In Fig. 1 the dotted centre lines of the arches and rib on plan represent the springing line on which the arch or rib curve is set up.

‡ The sections of the vault at the crown are shown in Fig. 1.

§ This is better seen in the vaulting of the crypt. I have made measured drawings of the crypt vaults, which I hope to be able to publish some day.

three-quarters of the circle, I could not think of an earlier date than the second quarter of the twelfth century.* But the profile in the bay in question is as shown in Fig. 3, the roll being disengaged to the

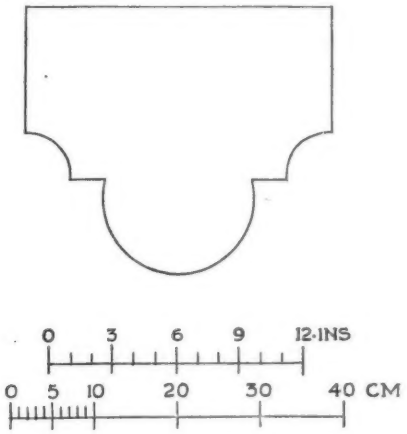



FIG. 3.—WINCHESTER, DIAGONAL RIB.

extent of only slightly more than the semicircle. The profile is similar to that of the diagonal ribs of the choir aisles of Durham,† built at least ten years before the Winchester tower fell. The structural system, too, of the Durham ‡ and Winchester vaults is the same, though the technique at Winchester is more advanced. It seems to me, therefore, that there is nothing in the character of the Winchester work which is in any way inconsistent with the date which *prima facie* is most probable. It is extremely unlikely that, in a city of the outstanding importance of Winchester at the beginning of the twelfth century, and in a cathedral abbey of such means as Winchester then possessed, the monks would leave a gaping void in the middle of their great church for some twenty years. On the grounds of architectural character and historic probability it must, I think, be regarded as certain that the bays of the transept near the crossing and the aisle vaults of these bays were built in the years immediately following the fall of the tower in 1107.

This view is confirmed by the study of the development of vaulted construction in the Norman Romanesque school, but the subject is too large to be more than mentioned here. Before the beginning of the war I had written a paper in which I make some attempt to sketch the course of this development, but I was waiting for a photograph of a vault in Normandy which one of my French friends was to take for me, and it would seem that the publication of the paper must be postponed until victory has crowned the heroism of France.

* Compare the profile of the diagonal rib in the vault of the chancel of St. John's, Devizes, which is very like Professor Moore's Fig. 8, though the roll at Devizes is disengaged to the extent of rather less of the complete circle than in Fig. 8. This Devizes vault does come within the second quarter of the twelfth century.

† The Durham ribs are considerably more massive, being 22 inches wide as against a little over 14 inches for the Winchester ribs.

‡ Compare Fig. 1 with the Durham drawing, Fig. 10, p. 298, in my *Beginnings*.

# ARCHITECTURAL ACOUSTICS.

By WALLACE C. SABINE, Sc.D., Dean, The Graduate School of Applied Science, Harvard University.

[The Royal Institute is indebted to the Board of Management of the Franklin Institute for permission to r print this Paper from their Journal, and for kindly lending the blocks of the illustrations.]

BECAUSE familiarity with the phenomena of sound has so far outstripped the adequate study of the problems involved, many of them have been popularly shrouded in a wholly unnecessary mystery. Of none, perhaps, is this more true than of architectural acoustics. The conditions surrounding the transmission of speech in an enclosed auditorium are complicated, it is true, but are only such as will yield an exact solution in the light of adequate data. It is, in other words, a rational engineering problem.

The problem of architectural acoustics is necessarily complex, and each room presents many conditions which contribute to the result in a greater or less degree, according to circumstances. To take justly into account these varied conditions, the solution of the problem should be quantitative, not merely qualitative; and to reach its highest usefulness and the dignity of an engineering science it should be such that its application can precede, not merely follow, the construction of the building.

In order that hearing may be good in any auditorium it is necessary that the sound should be sufficiently loud, that the simultaneous components of a complex sound should maintain their proper relative intensities, and that the successive sounds in rapidly moving articulation, either of speech or of music, should be clear and distinct, free from each other and from extraneous noises. These three are the necessary, as they are the entirely sufficient, conditions for good hearing. Scientifically the problem involves three factors: reverberation, interference, and resonance. As an engineering problem it involves the shape of the auditorium, its dimensions, and the materials of which it is composed.

Sound, being energy, once produced in a confined space, will continue until it is either transmitted by the boundary walls or is transformed into some other kind of energy, generally heat. This process of decay is called absorption. Thus, in the lecture-room of Harvard University, in which, and in behalf of which, this investigation was begun, the rate of absorption was so small that a word spoken in an ordinary tone of voice was audible for five and a half seconds afterwards. During this time even a very deliberate speaker would have uttered the twelve or fifteen succeeding syllables. Thus the successive enunciations blended into a loud sound, through which and above which it was necessary to hear and distinguish the orderly progression of the speech. Across the room this could not be done; even near the speaker it could be done only with an effort wearisome in the extreme if long maintained. With an audience filling the room the conditions were not so bad, but still not tolerable. This may be regarded, if one so chooses, as a process of multiple reflection from walls, from ceiling, and from floor, first from one and then another, losing a little at each reflection until ultimately inaudible. This phenomenon will be called reverberation, including, as a special case, the echo. It must be observed, however, that, in general, reverberation results in a mass of sound filling the whole room and incapable of analysis into its distinct reflections. It is thus more difficult to recognise and impossible to locate. The term "echo" will be reserved for that particular case in which a short, sharp sound is distinctly repeated by reflection, either once from a single surface, or several times from two or more surfaces. In the general case of reverberation we are concerned only with the rate of decay of the sound. In the special case of the echo we are concerned not merely with its intensity, but with the interval of time elapsing between the initial sound and the moment it reaches the observer. In the room mentioned as the occasion of this investigation no discrete echo was distinctly perceptible, and the case will serve excellently as an illustration of the more general type of reverberation. After preliminary gropings, first in the literature and then with several optical devices for measuring the intensity of sound, all established methods were abandoned. Instead, the rate of decay was measured by measuring what was inversely proportional to it—the duration of audibility of the reverberation, or, as it will be called here, the duration of audibility of the residual sound. These experiments may be explained to advantage here, for they will give more clearly than would abstract discussion an idea of the nature of reverberation. Broadly considered, there are two, and only two, variables in a room—shape (including size) and materials (including furnishings). In designing an auditorium an architect can give consideration to both; in repair work for bad acoustic conditions it is generally impracticable to change the shape, and only variations in materials and furnishings are allowable. This was, therefore, the line of work in this case. It was evident that, other things being equal, the rate at which the reverberation would disappear was proportional to the rate at which the sound was absorbed. The first work, therefore, was to determine the relative absorbing power of various substances. With an organ pipe as a constant source of sound, and a suitable chronograph for recording, the duration of audibility of a sound after the source had ceased in this room when empty was found to be 5·62 seconds. All the cushions from the seats in Sanders Theatre were then brought over and stored in the lobby. On bringing into the lecture-room a number of cushions, having a total length of 8·2 metres, the

duration of audibility fell to 5·33 seconds. On bringing in 17 metres the sound in the room after the organ pipe ceased was audible for but 4·94 seconds. Evidently the cushions were strong absorbents and rapidly improving the room, at least to the extent of diminishing the reverberation. The result was interesting and the process was continued. Little by little the cushions were brought into the room, and each time the duration of audibility was measured. When all the seats (436 in number) were covered, the sound was audible for 2·03 seconds. Then the aisles were covered, and then the platform. Still there were more cushions—almost half as many more. These were brought into the room, a few at a time, as before, and draped on a scaffolding that had been erected around the room, the duration of the sound being recorded each time. Finally, when all the cushions from a theatre seating nearly fifteen hundred persons were placed in the room—covering the seats, the aisles, the platform, the rear wall to the ceiling—the duration of audibility of the residual sound was 1·14 seconds. This experiment, requiring, of course, several nights' work, having been completed, all the cushions were removed and the room was in readiness for the test of other absorbents. It was evident that a standard of comparison had been established. Curtains of chenille, 1·1 metres wide and 17 metres in total length, were draped in the room. The duration of audibility was then 4·51 seconds. Turning to the data that had just been collected, it appeared that this amount of chenille was equivalent to 30 metres of Sanders Theatre cushions. Oriental rugs (Herez, Demirjik, and Hindoostanee) were tested in a similar manner, as were also cretonne cloth, canvas, and hair-felt. Similar experiments, but in a smaller room, determined the absorbing power of a man and of a

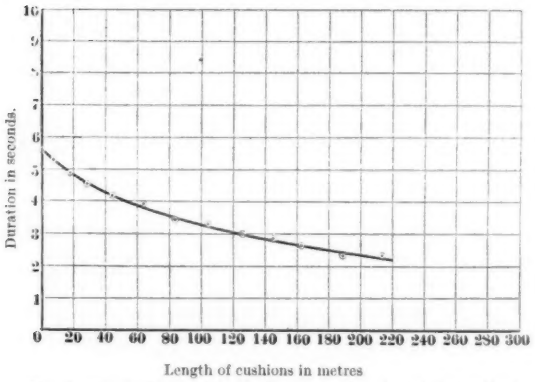



FIG. 1.—Curve showing the relation of the duration of the residual sound to the added absorbing material.

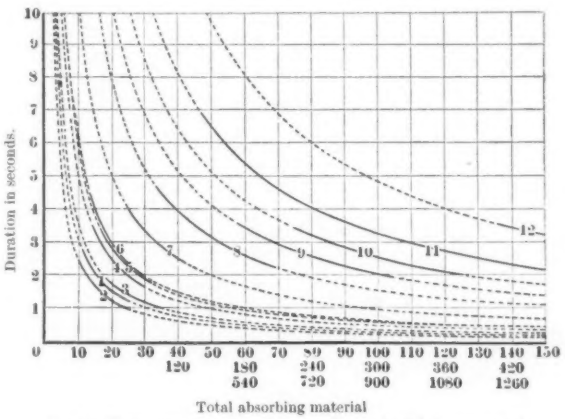



FIG. 3.—The curves of Figs. 8 and 9 entered as parts of their corresponding rectangular hyperbolas. Three scales are employed for the volumes by groups 1–7, 8–11, and 12.

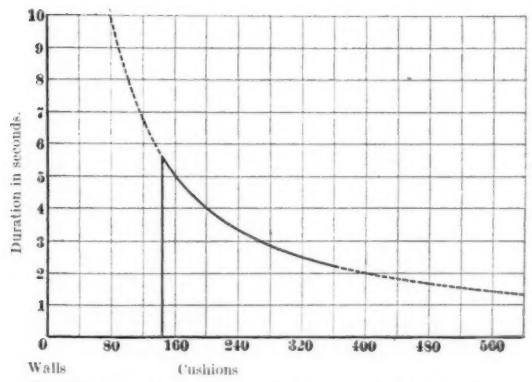



FIG. 2.—Curve 5 plotted as part of its corresponding rectangular hyperbola. The solid part was determined experimentally; the displacement of this to the right measures the absorbing power of the walls of the room.

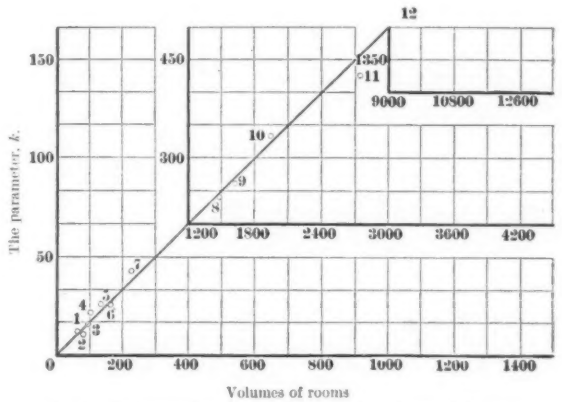



FIG. 4.—The parameters, $k$, plotted against the volumes of the rooms, showing the two proportional.

woman, always by determining the number of running metres of Sanders Theatre cushions that would produce the same effect. This process of comparing two absorbents by actually substituting one for the other is laborious, and it is given here only to show the first steps in the development of a method. Without going into details, it is sufficient here to say that this method was so perfected as to give not merely relative, but absolute, coefficients of absorption.

In this manner a number of coefficients of absorption were determined for objects and materials which could be brought into and removed from the room, for sounds having a pitch an octave above middle C. In the following table the numerical values are the absolute coefficients of the absorption :

| | |
|---|---|
| Oil paintings, inclusive of frames ... ... | 0·28 |
| Carpet rugs ... ... ... ... ... | 0·20 |
| Oriental rugs, extra heavy ... ... ... | 0·29 |
| Cheese-cloth ... ... ... ... ... | 0·019 |
| Cretonne cloth ... ... ... ... ... | 0·15 |
| Shelia curtains ... ... ... ... ... | 0·23 |
| Hair felt, 2·5 cm. thick, 8 cm. from wall ... | 0·78 |
| Cork, 2·5 cm. thick, loose on floor ... ... | 0·16 |
| Linoleum, loose on floor ... ... ... | 0·12 |

When the objects are not extended surfaces, such as carpets or rugs, but essentially spacial units, it is not easy to express the absorption as an absolute coefficient. In the following table the absorption of each object is expressed in terms of a square metre of complete absorption :

| | |
|---|---|
| Audience, per person ... ... ... ... | 0·44 |
| Isolated woman... ... ... ... ... | 0·54 |
| Isolated man ... ... ... ... ... | 0·48 |
| Plain ash settees ... ... ... ... | 0·039 |
| Plain ash settees, per single seat ... ... | 0·0077 |
| Plain ash chairs, " bent wood " ... ... | 0·0082 |
| Upholstered settees, hair and leather ... | 1·10 |
| Upholstered settees, per single seat ... ... | 0·28 |
| Upholstered chairs, similar in style ... ... | 0·30 |
| Hair cushions, per seat... ... ... ... | 0·21 |
| Elastic-felt cushions, per seat ... ... | 0·21 |

Of even greater importance was the determination of the coefficient of absorption of floors, ceilings, and wall surfaces. The accomplishment of this called for a very considerable extension of the method adopted. If the reverberation in a room as changed by the addition of absorbing material be plotted, the resulting curve will be found to be a portion of an hyperbola with displaced axes. An example of such a curve, as obtained in the lecture-room of the Fogg Art Museum, in Cambridge, is plotted in the diagram, Fig. 1. If now the origin of this curve be displaced so that the axes of coördinates are the asymptotes of the rectangular hyperbola, the displacement of the origin measures the initial absorbing power of the room, its floors, walls, and ceilings. Such experiments were carried out in a large number of rooms in which the different component materials entered in very different degrees, and an elimination between these different experiments gave the following coefficient of absorption for different materials :

| | |
|---|---|
| Open window ... ... ... ... ... | 1·000 |
| Wood sheathing (hard pine) ... ... ... | 0·061 |
| Plaster on wood-lath ... ... ... ... | 0·034 |
| Plaster on wire-lath ... ... ... ... | 0·033 |
| Glass, single thickness ... ... ... ... | 0·027 |
| Plaster on tile ... ... ... ... ... | 0·025 |
| Brick set in Portland cement ... ... ... | 0·025 |

If the experiments in these rooms are plotted in a single diagram, the result is a family of hyperbolæ showing a very interesting relationship to the volumes of the rooms. Indeed, if from these hyperbolæ the parameter, which equals the product of the coördinates, be determined, it will be found to be linearly proportional to the volume of the room. These results are plotted in Fig. 4, showing how strict the proportionality is even over a very great range in volume. We have thus at hand a ready method of calculating the reverberation for any room, its volume and the materials of which it is composed being known.

The first five years of the investigation were devoted to violin C, the C an octave above middle C, having a vibration frequency of 512 vibrations per second. This pitch was chosen because, in the art of telephony, it was regarded at that time as the characteristic pitch determining the conditions of articulate speech. The planning of Symphony Hall in Boston forced an extension of this investigation to notes over the whole range of the musical scale, three octaves below and three octaves above violin C.

In the very nature of the problem, the most important datum is the absorption coefficient of an audience, and the determination of this was the first task undertaken. By means of a lecture on one of the recent developments of physics, wireless telegraphy, an audience was thus drawn together and at the end of the lecture requested to remain for the experiment. In this attempt the effort was made to determine the coefficients for the five octaves from $C_2128$ to $C_6 2048$, including notes E and G in each octave. For several reasons the experiment was not a success. A threatening thunderstorm made the audience a small one, and the sultriness of the atmosphere made open windows necessary, while the attempt to cover so many notes, thirteen in all, prolonged the experiment beyond the endurance of the audience. While this experiment failed, another the following summer was more successful. In the year that had elapsed the necessity of carrying the investigation further than the limits intended became evident, and now the experiment was carried from $C_1 64$ to $C_7 4096$, but included only the C notes, seven notes in all. Moreover, bearing in mind the experiences of the previous summer, it was recognised that even seven notes would come dangerously near overtaxing the patience of the audience. Inasmuch as the coefficient of absorption for $C_4 512$ had already been determined six years before, in the investigations mentioned, the coefficient for this note was not redetermined. The experiment was therefore carried out for the lower three and the upper three notes of the seven. The audience on the night of tl is

experiment was much larger than that which came the previous summer, the night was a more comfortable one, and it was possible to close the windows during the experiment. The conditions were thus fairly satisfactory. In order to get as much data as possible, and in as short a time, there were nine observers stationed at different points in the room. These observers, whose kindness and skill it is a pleasure to acknowledge, had prepared themselves, by previous practice, for this one experiment. The results of the experiment are shown on the lower curve in Fig. 5. This curve gives the coefficient of absorption per person. It is to be observed that one of the points falls clearly off the smooth curve drawn through the other points. The observations on which this point is based were, however, much disturbed by a street car passing not far from the building, and the departure of this observation from the curve does not indicate a real departure in the coefficient, nor should it cast much doubt on the rest of the work, in view of the circumstances under which it was secured. Counteracting the, perhaps, bad impression which this point may give, it is a considerable satisfaction to note how accurately the point for C 512, determined six years before by a different set of observers, falls on the smooth curve through the remaining points. In the audience on which these observations were taken there were 77 women and 105 men. The courtesy of the audience in remaining for the experiment and the really remarkable silence which they maintained are gratefully acknowledged.

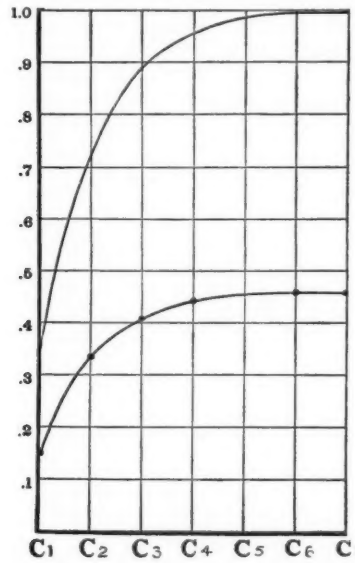



FIG. 5.—The absorbing power of an audience for different notes. The lower curve represents the absorbing power of an audience per person. The upper curve represents the absorbing power of an audience per square metre as ordinarily seated. The vertical ordinates are expressed in terms of total absorption by a square metre of surface. For the upper curve the ordinates are thus the ordinary coefficients of absorption. The several notes are at octave intervals, as follows: $C_1$64, $C_2$128, $C_3$ (middle C) 256, $C_4$512, $C_5$1024, $C_6$2048, $C_7$4096.

The next experiment was on the determination of the absorption of sound by wood sheathing. It is not an easy matter to find conditions suitable for this experiment. The room in which the absorption by wood sheathing was determined in the earlier experiments was not available for these. It was available then only because the building was new and empty. When these more elaborate experiments were under way the room became occupied, and in a manner that did not admit of its being cleared. Quite a little searching in the neighbourhood of Boston failed to discover an entirely suitable room. The best one available adjoined a night lunch-room. The night lunch was bought out for a couple of nights, and the experiment was tried. The work of both nights was much disturbed. The traffic past the building did not stop until nearly two o'clock, and began again at four. The interest of those passing on foot throughout the night, and the necessity of repeated explanations to the police, greatly interfered with the work. This detailed statement of the conditions under which the experiment was tried is made by way of explanation of the

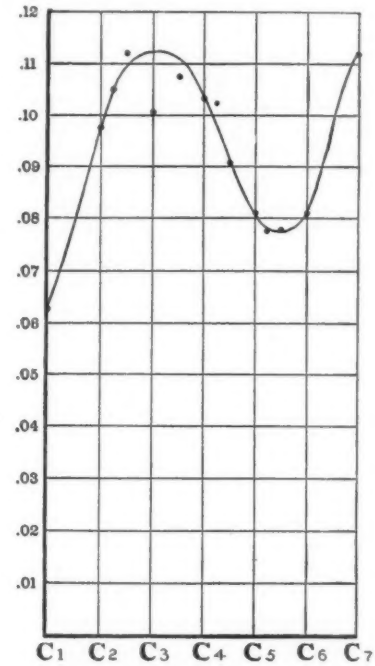



FIG. 6.—The absorbing power of wood sheathing, two centimetres thick, North Carolina pine. The observations were made under very unsuitable conditions. The absorption is here due almost wholly to yielding of the sheathing as a whole, the surface being shellacked, smooth and non-porous. The curve shows one point of resonance within the range tested, and the probability of another point of resonance above. It is not possible now to learn as much in regard to the framing and arrangement of the studding in the particular room tested as is desirable. $C_3$ (middle C) 256.

irregularity of the observations recorded on the curve, and of the failure to carry this particular line of work further. The first night seven points were obtained for the seven notes $C_1$64 to $C_7$4096. The reduction of these results on the following day showed variations indicative of maxima and minima, which, to be accurately located, would require the determination of intermediate points. In the experiment the following night points were determined for the E and G notes in each octave between $C_2$128 and $C_6$2048. Other points would have been determined, but time did not permit. It is obvious that the intermediate points in the lower and in the higher octave were desirable, but no pipes were to be had on such short notice for this part of the range, and in their absence the data could not be obtained. In the diagram, Fig. 6, the points lying on the vertical lines were determined the first night. The points lying between the vertical lines were determined the second night. The accuracy with which these points fall on a smooth curve is, perhaps, all that could be expected in view of the difficulty under which the observations were conducted and the limited time available. One point in particular falls far off from this curve, the point for $C_3$256, by an amount which is, to say the least, serious, and which can be justified only by the conditions under which the work was done. The general trend of the curve seems, however, established beyond reasonable doubt. It is interesting to note that there is one point of maximum absorption, which is due to resonance between the walls and the sound, and that this point of maximum absorption lies in the lower part, though not in the lowest part, of the range of pitch tested. It would have been interesting to determine, had the time and facilities permitted, the shape of the curve beyond $C_7$4096, and to see if it rises indefinitely, or shows, as is far more likely, a succession of maxima.

The experiment was then directed to the determination of the absorption of sound by cushions, and for this purpose return was made to the constant temperature room. Working in the manner indicated in the earlier papers for substances which could be carried in and out of a room, the curves represented in Fig. 7 were obtained. Curve 1 shows the absorption coefficient for the Sanders Theatre cushions, with which the whole investigation was begun ten years ago. These cushions were of a particularly open grade of packing, a sort of wiry grass or vegetable fibre. They were covered with canvas ticking, and that, in turn, with a very thin cloth covering. Curve 2 is for cushions borrowed from the Phillips Brooks House. They were of a high grade, filled with long, curly hair, and covered with canvas ticking, which was, in turn, covered by a long nap plush. Curve 3 is for the cushions of Appleton Chapel, hair covered with a leatherette, and showing a sharper maximum and a more rapid diminution in absorption for the higher frequencies, as would be expected under such conditions. Curve 4 is probably the most interesting, because for more standard commercial conditions ordinarily used in churches. It is to be observed that all four curves fall off for the higher frequencies, all show a maximum located within an octave, and three of the curves show a curious hump in the second octave. This break in the curve is a genuine phenomenon, as it was tested time after time. It is perhaps due to a secondary resonance, and it is to be observed that it is the more pronounced in those curves that have the sharper resonance in their principal maxima.

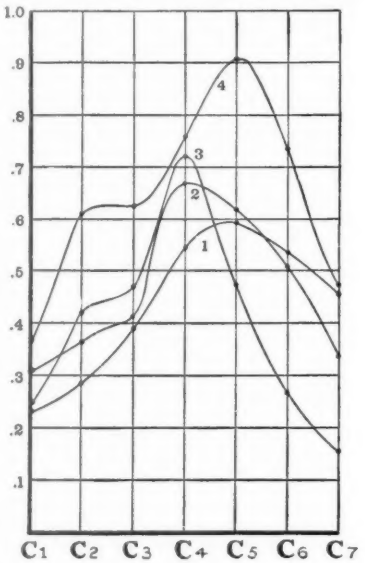



FIG. 7.—The absorbing power of cushions. Curve 1 is for "Sanders Theatre" cushions of wiry vegetable fibre, covered with canvas ticking and a thin cloth. Curve 2 is for "Brooks House" cushions of long hair, covered with the same kind of ticking and plush. Curve 3 is for "Appleton Chapel" cushions of hair, covered with ticking and a thin leatherette. Curve 4 is for the elastic felt cushions of commerce, of elastic cotton, covered with ticking and short nap plush. The absorbing power is per square metre of surface. $C_3$ (middle C) 256.

In both articulate speech and in music the source of sound is rapidly and, in general, abruptly changing in pitch, quality, and loudness. In music one pitch is held during the length of a note. In articulate speech the unit or element of constancy is the syllable. Indeed, in speech it is even less than the length of a syllable, for the open vowel sound which forms the body of a syllable usually has a consonantal opening and closing. During the constancy of an element, either of music or of speech, a train of sound waves spreads spherically from the source, just as a train of circular waves spreads outward from a rocking boat on the surface of still water. Different portions of this train of spherical waves strike different surfaces of the auditorium and are reflected. After such reflection they begin to cross each other's paths. If their paths are so different in length that one train of waves has entirely passed before the other arrives at a particular point, the only phenomenon at that point is prolongation of the sound. If the space between the two trains of waves be sufficiently great, the effect will be

that of an echo. If there be a number of such trains of waves thus widely spaced, the effect will be that of multiple echoes. On the other hand, if two trains of waves have travelled so nearly equal paths that they overlap, they will, dependent on the difference in length of the paths which they had travelled, either reinforce or mutually destroy each other. Just as two equal trains of water waves crossing each other may entirely neutralise each other if the crest of one and

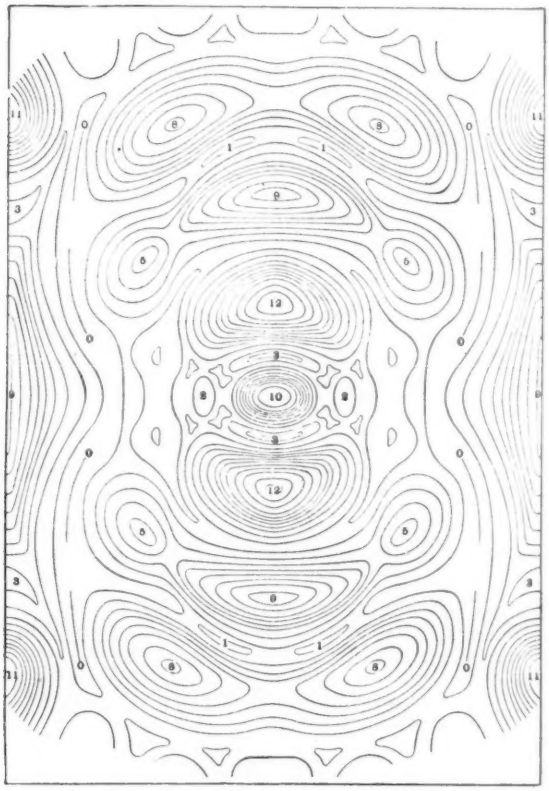


FIG. 8.—Distribution of intensity on the head level in a room with a barrel-shaped ceiling, with centre of curvature on the floor level.

the trough of the other arrive together, so two sounds, coming from the same source, in crossing each other may produce silence. This phenomenon is called interference, and is a common phenomenon in all types of wave motion. Of course, this phenomenon has its complement. If the two trains of water waves so cross that the crest of one coincides with the crest of the other and trough with trough, the effects will be added together. If the two sound waves be similarly retarded, the one on the other, their effects will also be added. If the two trains of waves be equal in intensity, the combined intensity will be quadruple that of either of the trains separately, as above explained, or zero, depending on their relative retardation. The effect of this phenomenon is to produce regions in an auditorium of loudness and regions of comparative or even complete silence. It is a partial explanation of the so-called deaf regions in an auditorium.

It is not difficult to observe this phenomenon directly. It is difficult, however, to measure and record the phenomenon in such a manner as to permit of an accurate chart of the result. Without going into the details of the method employed, the result of these measurements for a room very similar to the Congregational Church in Naugatuck, Connecticut, is shown in the accompanying chart. The room experimented in was a simple, rectangular room with plain side walls and ends and with a barrel or cylindrical ceiling. The result is clearly represented in Fig. 8, in which the intensity of the sound has been indicated by contour lines in the manner employed in the drawing of the geodetic survey maps. The phenomenon indicated in these diagrams was not ephemeral, but was constant so long as the source of sound continued, and repeated itself with almost perfect accuracy day after day. Nor was the phenomenon one which could be observed merely instrumentally. To an observer moving about in the room it was quite as striking a phenomenon as the diagrams suggest. At the points in the room indicated as high maxima of intensity in the diagram the sound was so loud as to be disagreeable, at other points so low as to be scarcely audible. It should be added that this distribution of intensity is with the source of sound at the centre of the room. Had the source of sound been at one end and on the axis of the cylindrical ceiling, the distribution of intensity would still have been bilaterally symmetrical, but not symmetrical about the transverse axis.

When a source of sound is maintained constant for a sufficiently long time, a few seconds will ordinarily suffice: the sound becomes steady at every point in the room. The distribution of the intensity of sound under these conditions is called the interference system, for that particular note, of the room or space in question. If the source of sound is suddenly stopped, it requires some time for the sound in the room to be absorbed. This prolongation of sound after the source has ceased is called reverberation. If the source of sound, instead of being maintained, is short and sharp, it travels as a discrete wave or group of waves about the room, reflected from wall to wall, producing echoes. In the Greek theatre there was ordinarily but one echo, "doubling the case ending," while in the modern auditorium there are many, generally arriving at a less interval of time after the direct sound and therefore less distinguishable, but stronger and therefore more disturbing.

The formation and the propagation of echoes may be admirably studied by an adaptation of the so-called *schlieren-Methode* device for photographing air disturbances. It is sufficient here to say that the adaptation of this method to the problem in hand consists in the construction of a model of the auditorium

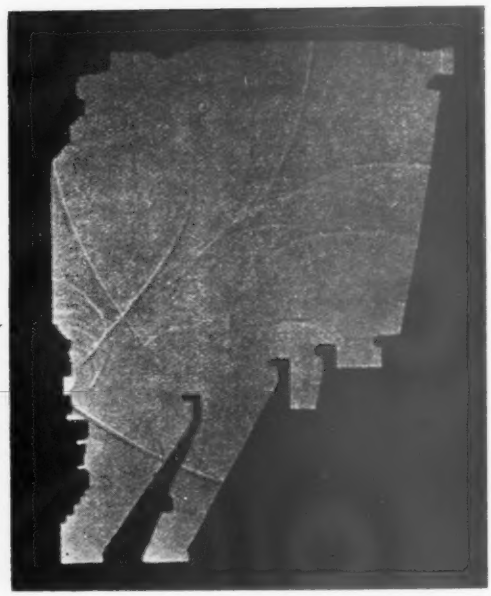


FIG. 11.

FIG. 12.

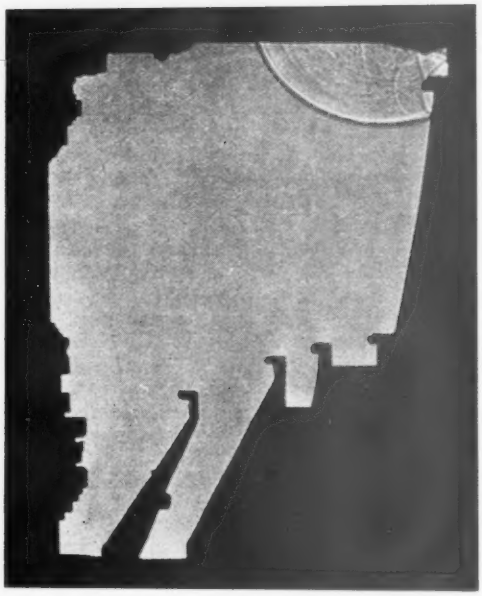


FIG. 9.

FIG. 10.

to be studied to proper scale, and investigating the propagation through it of a proportionately scaled sound wave. To examine the formation of echoes in a vertical section, the sides of a model are taken off and, as the sound is passing through it, it is illuminated instantaneously by the light from a very fine and somewhat distant electric spark. In the accompanying illustrations, reduced from the photographs, the enframing silhouettes are shadows cast by the model, and all within are direct photographs of the actual sound wave and its echoes. The four photographs show the sound and its echoes at different stages in their propagation through the room, the particular auditorium under investigation being the New Theatre in New York. It is not difficult to identify the master wave and the various echoes which it generates, nor, knowing the velocity of sound, to compute the interval at which the echo is heard.

To show the gene ation of echoes and their propagation in a horizontal plane, the ceiling and floor of the model are removed and the photograph taken in a vertical direction. The photographs shown in Figs. 13 to 16 show the echoes produced in the horizontal plane passing through the marble parapet in front of the box.

While these several factors, reverberation, interference, and echo, in an auditorium at all complicated are themselves complicated, nevertheless they are capable of an exact solution, or, at least, of a solution as accurate as are the architect's plans in actual construction. And it is entirely possible to calculate in advance of construction whether or not an auditorium will be good, and, if not, to determine the factors contributing to its poor acoustics and a method for their orrection.

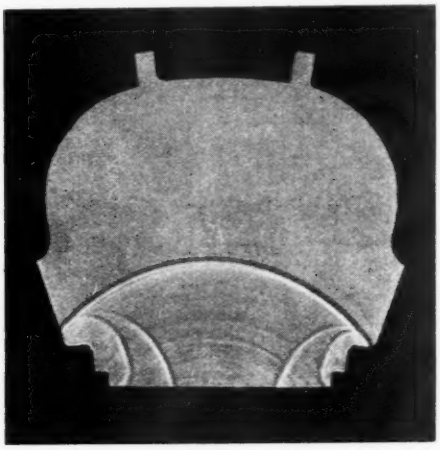


FIG. 13.

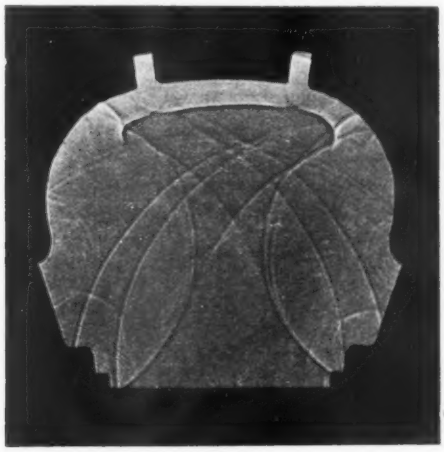


FIG. 15.

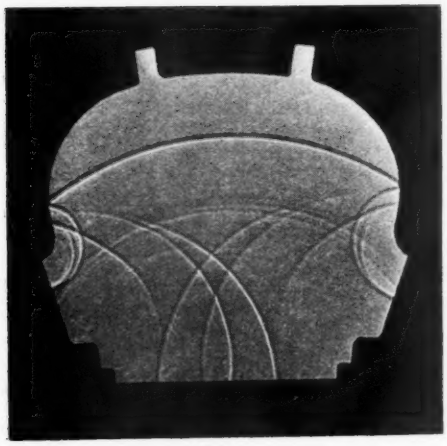


FIG. 14

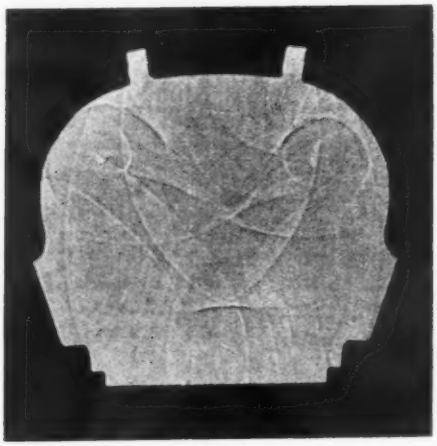


FIG. 16.

9 CONDUIT STREET, LONDON, W., 13*th January* 1917.

## CHRONICLE.

### The R.I.B.A. Record of Honour: Thirty-ninth List.

*Fallen in the War*

BENNETT, Lieut. JAMES, Royal Engineers [*A.*]. Killed in action on 28th November.

STURGEON, Captain ROBERT VICTOR [*A.*]. At first stated to be missing; War Office now report that they are obliged to consider that he was killed on 10th March last.

DURRANT, Captain ARTHUR MICHAEL, Royal Engineers [*A.*]. Killed in action.

*Severely Wounded and Missing.*

HONAN, Captain MATTHEW, South Lancashire Regiment [*A.*], of 36 Dale Street, Liverpool. Severely wounded and reported missing in the recent fighting.

Captain Honan obtained a commission in the South Lancashire Regiment in 1914 and was promoted Captain in five months. He went out to Gallipoli with the 29th Division, being attached to the Lancashire Fusiliers, and was mentioned in despatches "for great coolness, initiative and conspicuous bravery in action." He was transferred into the Regular Army in October 1915, joining the South Lancashire Regiment, and went to the Front in France early in September.

*Wounded*

MCLEAN, Lieut. ARTHUR JOHN, Machine Gun Corps [*A.*]. Severely wounded on 12th October. Progressing favourably.

Lieut. McLean was seconded from the South Lancashire Regiment to the Machine Gun Corps and was later promoted full Lieutenant. He has lost two brothers in the War: 2nd Lieut. Angus McLean, Wilts Regt., killed at Hooge, 23rd June 1915, and 2nd Lieut. Raymond McLean, Seaforths, killed at Beaumont Hamel, 13th Nov. 1916.

*Awards for Distinguished Service.*

HUBBACK, Brigadier-General ARTHUR [*F.*] had the honour of being received by the King at Buckingham Palace on the 30th ult. and was invested by His Majesty with the insignia of Companion of the Most Distinguished Order of St. Michael and St. George.

DOUGLAS, Major J. W., Northumbrian R.E., Member of the Northern A.A.: awarded the D.S.O., and the Serbian Order of the White Eagle.

MAUCHLIN, Captain R., Member of the Northern A.A.: awarded the Military Cross.

WATERHOUSE, Captain MICHAEL, Notts Yeomanry (Sherwood Rangers), Notts and Derby Mounted Brigade: awarded the Military Cross. Captain Waterhouse is the son of Mr. Paul Waterhouse [*F.*], and grandson of the late Alfred Waterhouse, R.A.

WEBB, Captain MAURICE, Royal Engineers: awarded the Military Cross. Captain Webb is the son of Sir Aston Webb, K.C.V.O., C.B., R.A. [*F.*].

GRELLIER, Captain CECIL, Hampshire Regiment [*Student*], nephew of Mr. William Grellier [*F.*], has been awarded the Serbian Order of the White Eagle. He has also been recommended by the British Command for gallant conduct in action.

Captain Grellier, in command of a company, was left with fifty men to hold with the Dublins a hill on the borders of Serbia and Bulgaria, whilst the remainder of the battalion retired to a position in the rear. Shelled by the enemy's guns and practically without food or water for more than forty-eight hours, they held the position and joined the battalion on the 8th or 9th December without having suffered very serious losses.

*Mentioned in Despatches.*

CRAIK, Captain DAVID MCLEOD, Royal Engineers [*F.*]

DURRANT, The late Captain ARTHUR MICHAEL, Royal Engineers, M.C. [*A.*]

*Serving with the Forces.*

The following is the Thirty-ninth List of Members, Licentiates, and Students R.I.B.A. serving with the Forces, the total to date being 69 Fellows, 506 Associates, 307 Licentiates, and 291 Students:—

FELLOW.

Gill, Charles Lovett: O.T.C., Artists' Rifles.

ASSOCIATES.

Hooker, W.: 2nd Lieut., R.E.
Wright, E. L.: Army Service Corps (M.T.).
Perkins, Cecil H.: 2nd Lieut., R.E.
Metcalfe, C. B.: Cheshire Regt.
Fowell, J. C.: Sub-Lieut., R.N.V.R.
Welch, H. A.: R.N.A.S.

LICENTIATES.

Ardley, C.E.: R.N.A.S.
Fermaud, Edmund Auguste: Essex Regt.
Porter, Bernard A.: 2nd Lieut. (on probation), R.G.A.

STUDENTS.

McNichol, J.: 2nd Lieut., R.G.A.
Gregory, Hubert: R.F.A.
Dartnall, J. A.: R.E. Cadet Unit.
Ardley, C. E.: R.N.A.S.

*Promotions, &c.*

Hill, Captain D., member of the Northern A.A., has been promoted Brigade Major.
McNichol, J. [*Student*], to 2nd Lieut., R.G.A.
Crone, H. C. [*A.*], Capt. R.E.
Williams, L. E. [*A.*], from Artists' Rifles to 2nd Lieut., R.E.
Smithers, Lt. Alec. [*A.*] to Capt., R.A.
Hunter, J. Douglas [*Licentiate*], to 2nd Lieut., R.G.A.
Barnard, Capt. L. W. [*F.*], transferred to Artizan Works Co., R.E.

### Informal Conferences at the Institute.

The Council have favourably considered the suggestion made by Professor Lethaby at the Opening Meet-

ing of the Session (see JOURNAL, 11th November, page 8) and have arranged for a series of informal conferences to be held at the Institute on subjects of interest to architects and of importance to the public. The conferences will be held on Wednesdays, at 3.30 p.m., at fortnightly intervals, beginning Wednesday, 24th January. The following is a list of subjects and dates as far as at present arranged, together with the names of the openers of discussions and Chairmen of Meetings :—

*24th January.*—"Architecture and Civilisation." Opener, Professor W. R. Lethaby [*F.*]; Chairman, Mr. F. W. Troup [*F.*].

*7th February.*—"Education of the Architect." Opener, Mr. Robert Atkinson [*F.*]; Chairman, Mr. Reginald Blomfield, R.A. [*F.*].

*21st February.*—"Education of the Architect" (*continued*). Opener, Mr. A. E. Richardson [*F.*]; Chairman, Mr. H. V. Lanchester [*F.*].

*7th March.*—"The Control of Street Architecture." Opener, Sir John Burnet, R.S.A., LL.D. [*F.*]; Chairman, Sir Aston Webb, K.C.V.O., C.B., R.A. [*F.*].

*21st March.*—"New Materials and Methods as Influencing Design." Opener, Mr. H. D. Searles-Wood [*F.*]; Chairman, Mr. E. Guy Dawber [*F.*].

Many well-known architects have consented to take part in the conferences and the Council hope that there will be good attendances of members.

### Architects and the National Service Department.

One of the tasks to be grappled with by the new National Service Department will doubtless be the organisation of building labour. In anticipation of activities in this direction the President, Mr. Ernest Newton, A.R.A., has addressed a letter to Mr. Neville Chamberlain, Director-General of National Service, assuring him that he may count upon the assistance of the Royal Institute and its Allied Societies all over the United Kingdom. The restrictions put on private building in order to secure labour for urgent war work lose much of their value unless the labour so displaced can be transferred to where there is a shortage. The organisation of labour only is not sufficient; the organisation of those who direct labour is of equal importance. The President calls Mr. Chamberlain's attention to the fact that there are a large number of architects not available for military service competent to do work of great national importance, but their talents seem likely to be wasted for want of organisation. He urges that "they should be employed to design and carry out buildings required for war purposes, that contracts for these buildings should be widely distributed amongst contractors who are in a sufficiently large way of business to carry them out, and that as many of the smaller firms as possible should be employed as sub-contractors. "It is not claimed," he continues, "that by following this programme employment will be found for everyone competent for the purpose, but it will certainly be the means of employing a very large number of men on work to which they are accustomed and which they can perform with immense advantage to the State. At present this talent and business capacity are largely wasted, and unnecessary unemployment and even distress result." The letter, in conclusion, mentions that it is proposed shortly to ask Mr. Chamberlain to receive a representative deputation on the subject. Mr. Chamberlain has replied expressing his thanks for the letter, and promising that it shall receive attention.

### American Help for A.B.S. War Fund.

Through the sympathy and goodwill of a number of Boston architects headed by Mr. Ralph Adams Cram [*Hon. Corr. M.*], President of the Boston Society of Architects, the War Fund of the Architects' Benevolent Society has benefited to the extent of £49 7*s.* 4*d.* This sum represents half the proceeds of a theatrical performance recently given in Boston in which several architects took part. The proceeds have been divided equally between the British Fund and the Fund for French architects, and the former's share, sent by Mr. Cram to Mr. Ernest Newton, has been placed to the credit of the A.B.S. War Fund. Mr. Cram in sending the donation writes that for some curious reason architects in America are also feeling the war, though, of course, not to the same extent as in the belligerent countries. "Frankly," he continues, "I wish we were. I mean to say I should welcome any degree of adversity if only it followed from our participation in the War. England and her Allies are fighting for us equally with the other Allied Christian nations of Europe." Mr. Cram has on many occasions given eloquent expression to his sympathy with the cause of the Entente Allies, notably in his impassioned Address to the Victorian Club at Boston in the early days of the War.* American sympathy is very precious to us, and the generous form it has taken with the Boston architects will be highly appreciated and gratefully remembered by the profession both here and in France.

### Building By-Laws.

Mr. Gordon Allen [*F.*] in a letter which has appeared in *The Times* and other papers this week calls attention to the increasingly urgent need for revision of existing building by-laws.

Even at the present time (Mr. Allen says) a certain amount of building is going on, and must go on, for the lamentable shortage of cottages almost everywhere has become a serious menace to the production of food and other necessary commodities. And there is not the slightest doubt that this house famine is largely due to the building regulations now in force, which have had the effect of deterring or adding needless hardships to the efforts of cottage-builders. Both the cost of building and the rate of interest are at present so high—and will probably remain so after the war—that the abolition of many of these out-of-date and inconsistent enactments has become a question of national importance. Having been founded on the "Model" series issued forty years ago by the Local Government Board, all building by-laws have long become obsolete. They take no account of modern improvements or the use of new materials (such as concrete), and it is no exaggeration to say that most of the progress made in the

* Printed in full in the JOURNAL R.I.B.A. for 23rd January, 1915.

way of economical construction has been dependent on loopholes that may be found in them. These by-laws were originally drawn up for governing building procedure in town areas; they have mischievous consequences when applying in rural districts. To keep up a high sanitary standard and to prevent flimsy construction is essential. But some of the present limitations, however imperative they may be in crowded centres, are unnecessary in the country, where buildings are often of a single story and far apart from each other. The danger of fire or infectious diseases spreading to neighbours is non-existent.

How inconsistent the "ridiculous" by-laws are can be seen in some neighbourhoods where a different set is in operation on opposite sides of the same street. Then take as an instance the question of room heights. This is an important matter where cost is the main factor (as it always is when cottages are being considered), for high rooms mean expensive high walls. Some local authorities insist on ceilings being 9 feet up, but say nothing as to the length and width of rooms, although floor space is far more essential than abnormal loftiness. Rooms 7 feet 6 inches or 8 feet high are much warmer and cosier, and can be equally well ventilated by a proper arrangement of opening windows. And a low cottage, besides being cheaper than a high one, is more in accord with surroundings of hedgerow and coppice. There are districts in which the tops of windows may be 6 feet above the floor; elsewhere this height has to be 7 feet, and sometimes 7 feet 6 inches (which once cost a client of mine an extra £100). As an actual example of the waste of money caused by differing drainage regulations I can mention two groups of munition workers' cottages I have recently been engaged on, which were built within a few miles of each other by the same contractor. The varying by-laws made a difference for the drains alone of more than £20 per dwelling.

### Carpenters' Hall Lectures.

A course of ten lectures illustrated by lantern photographs, etc., will be given on Wednesday evenings from January to April 1917, at 7.15 p.m., at Carpenters' Hall, London Wall, admission free by ticket to be obtained from Mr. J. Hutton Freeman, Clerk to the Company. The dates, subjects, and lecturers are as follows:—

Jan. 31.—"What I have learnt from the Care of Ancient Buildings," by Mr. Thackeray Turner, F.S.A. [*F.*].
Feb. 7.—"Wonder of Work in War Time," by Mr. Joseph Pennell.
Feb. 14.—"Samuel Pepys—Secretary of the Navy—a Lover of Music" (Musical Illustrations), by Sir Frederick Bridge, C.V.O., Mus.Doc.
Feb. 21.—"Scottish Houses of Five Centuries," by Mr. Lawrence Weaver, F.S.A. [*Hon. A.*].
Feb. 28.—"An Old Kentish House," by Mr. M. H. Baillie Scott.
Mar. 7.—"Tradition of Mural Painting," by Mr. George Clausen, R.A.
Mar. 14.—"Some Recent Additions to the National Collections," by Mr. Charles Aitken.
Mar. 21.—"Character in Building," by Mr. Herbert W. Wills [*F.*].
Mar. 28.—"Building and Furnishing a House—The Right Way and the Wrong Way," by Mr. C. Lewis Hind.
Apr. 4.—"British Forestry—Past and Future," by Professor Wm. Somerville, D.Sc., M.A., F.L.S.

## MINUTES.

At a General Meeting (Business) held Monday, 8th January 1917, at 4 p.m.—Present, Mr. Alfred W. S. Cross, M.A. Cantab., *Past Vice-President*, in the Chair, and several Fellows (including members of the Council) and Associates—the Minutes of the Meeting held 18th December were taken as read and signed as correct.

The Chairman having announced that since the last meeting news had been received that the following members had been killed in action—viz., Lieut. James Bennett, Royal Engineers, and Captain Robert Victor Sturgeon, *Associates*—it was RESOLVED, that the deepest regrets of the Institute for their loss be entered on the Minutes, and that a message of sympathy and condolence be sent to their relatives.

The decease was also announced of Robert Henry, *Associate*, elected 1889.

The following candidates were elected by show of hands, under By-law 9:

AS FELLOWS:—

ERRINGTON: CHARLES SEPTIMUS [*Assoc.* 1895], Newcastle-upon-Tyne.
SWASH: FRANK STANLEY [*Assoc.* 1912], Newport, Mon.
TRAVERS: WILFRID IRWIN [*Assoc.* 1906].

The Chairman announced that the Council had arranged for a series of informal conferences to take place at the Institute on subjects of interest to architects [see p. 78].

The proceedings closed and the meeting separated at 4.10 p.m.

## NOTICES.

### General Meeting, 5th February: Royal Gold Medal, 1917.

The Fourth General Meeting (Ordinary) of the Session 1916–17 will be held Monday, 5th February 1917, when the Chair will be taken at 4.30 p.m. precisely, for the following purposes:—

To read the Minutes of the General Meeting (Business) held Monday, 8th January 1917; formally to admit members attending for the first time since their election; to announce the names of candidates nominated for election.

To announce the name of the person the Council propose to submit to His Majesty as a fit recipient of the ROYAL GOLD MEDAL for 1917.

### Election of Members, 5th March 1917.

In accordance with the provisions of By-law 8, the names and addresses of the following applicants for membership are published for the information of members. Notice of any objection or other communication respecting them must be sent to the Secretary R.I.B.A. for submission to the Council prior to Monday, 5th February:—

AS FELLOWS (2).

MORRIS: PERCY [*Cates Prizeman* 1897, *Associate* 1897], County Architect (Education); 1 Blackhall Road and 2 Heavitree Park, Exeter.
WHEELER: CHRISTOPHER WILLIAM FREDERICK [*Associate* 1902], at present serving as Lieut., Army Service Corps; 7 Stone Buildings, Lincoln's Inn (office now closed); and "Melrose," St. James Road, Sutton, Surrey.

### Member's Partnership Notice.

Mr. George Hubbard [*F.*] writes that he has taken his son, Mr. Philip Waddington Hubbard, B.A. Cantab., into partnership, together with his assistant, Mr. William Charles Symes, P.A.S.I., who has been with him for over twenty years. The style of the firm will be known in future as George Hubbard & Son; the address remains as before, 112 Fenchurch Street, E.C.

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